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similar to that caused by increased temperature, but without elevated temperature. Although details of the mechanism of interaction of EM fields with cells remain unknown, the induction of the stress response appears to be an appropriate cellular response to a stimulus that is not normally part of its environment, and this may well provide a clue to the mechanisms involved.

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MS-20-4

THE BIOLOGICAL EFFECTS OF MICROWAVE RADIATION. S. Kwee[1] and P. Raskmark[2]. [1]Institute of Medical Biochemistry, University of Aarhus, DK-8000 Aarhus C, Denmark. [2]Institute of Communication Technology, Aalborg University, DK-9220 Aalborg Ø, Denmark.

In recent times the use of mobile telephones has accelerated, resulting in an increasing exposure of the environment to weak radiofrequency (RF) fields, transmitted from these devices.

In previous work we showed that cell growth is affected by exposure to weak electromagnetic (ELF) fields[1]. Consequently the next thing to investigate was, if EM fields generated by microwave radiation, would have a similar effect on cell proliferation.

The field was generated by signal simulation of the Global System for Mobile communications (GSM) of 960 MHz. Cell cultures, growing in microtiter plates, were exposed in a specially constructed chamber, a Transverse Electromagnetic (TEM) cell. The Specific Absorption Rate (SAR) values for each cell well were calculated for this exposure system[2].

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MS-20-5

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The characteristic and discrete energies $h\nu$ found as emission and absorption of electromagnetic radiation by atoms and molecules extend to X-ray energies. As high-energy electrons strike the piece of metal in an X-ray tube, electrons are knocked out of the inner energy shell of the atoms. These vacancies are then filled by electrons from the second or third shell; emitted in the process are X rays having $h\nu$ values that correspond to the energy differences of the shells. One therefore observes not only the continuous spectrum of the bremsstrahlung discussed above but also X-ray emissions of discrete energies $h\nu$ that are characteristic of the specific elemental composition of the metal struck by the energetic electrons in the X-ray tube.

Transparency of water to visible light

The discrete electromagnetic radiation energies $h\nu$ emitted or absorbed by all substances reflect the discreteness of the internal energies of all material things. This means that window glass and water are transparent to visible light; they cannot absorb these visible light quanta because their internal energies are such that no energy difference between a higher and a lower internal state matches the energy $h\nu$ of visible light. Figure 3 shows as an example the coefficient of absorption of water as a function of frequency ν of electromagnetic radiation. Above the scale of frequencies, the corresponding scales of photon energy $h\nu$ and wavelength λ are given. An absorption coefficient $\alpha = 10^{-4}$ cm^{-1} means that the intensity of electromagnetic radiation is only one-third its original value after passing through 100 metres of water. When $\alpha = 1$ cm^{-1}, only a layer one centimetre thick is needed to decrease the intensity to one-third its original value, and, for $\alpha = 10^3$ cm, a layer of water having a thickness of this page is sufficient to attenuate electromagnetic radiation by that much. The transparency of water to visible light, marked by the vertical dashed lines, is a remarkable feature that is significant for life on Earth.

From J.D. Jackson, *Classical Electrodynamics*, copyright © 1975 by John Wiley & Sons, Inc.

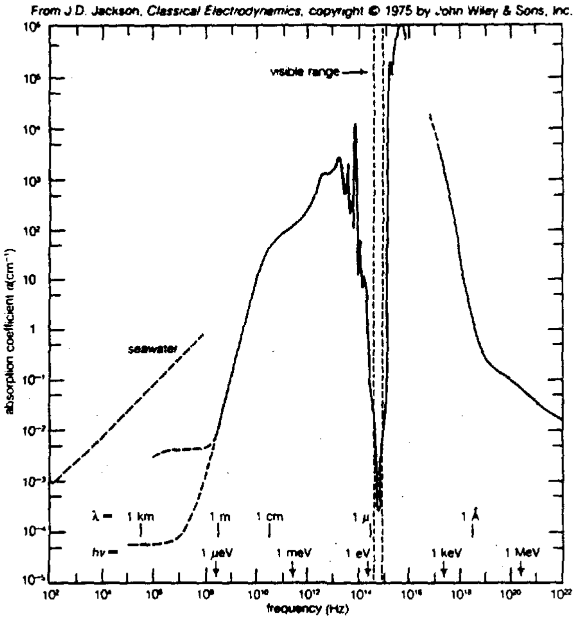

Figure 3: *The absorption coefficient for liquid water as a function of frequency.*
Also shown as abscissas are an energy scale (arrows) and a wavelength scale (vertical lines). The visible region of the frequency spectrum is indicated by the vertical dashed lines. The absorption coefficient for seawater is denoted by the dashed diagonal line at the left. The scales are logarithmic in both directions.

All things look so different and have different colours because of their different sets of internal discrete energies, which determine their interaction with electromagnetic radiation. The words *looking* and *colours* are associated with the human detectors of electromagnetic radiation, the eyes. Since there are instruments available for detecting electromagnetic radiation of any frequency, one can imagine that things "look" different at all energies of the spectrum because different materials have their own characteristic sets of discrete internal energies. Even the nuclei of atoms are composites of other elementary particles and thus can be excited to many discrete internal energy states. Since nuclear energies are much larger than atomic energies, the energy differences between internal energy states are substantially larger, and the corresponding electromagnetic radiation quanta $h\nu$ emitted or absorbed when nuclei change their energies are even bigger than those of X rays. Such quanta given off or absorbed by atomic nuclei are called gamma rays (see *The electromagnetic spectrum* above).

PROPERTIES AND BEHAVIOUR

Scattering, reflection, and refraction. If a charged particle interacts with an electromagnetic wave, it experiences a force proportional to the strength of the electric field and thus is forced to change its motion in accordance with the frequency of the electric field wave. In doing so, it becomes a source of electromagnetic radiation of the same frequency, as described in the previous section. The energy for the work done in accelerating the charged particle and emitting this secondary radiation comes from and is lost by the primary wave. This process is called scattering.

Since the energy density of the electromagnetic radiation is proportional to the square of the electric field strength and the field strength is caused by acceleration of a charge, the energy radiated by such a charge oscillator increases with the square of the acceleration. On the other hand, the acceleration of an oscillator depends on the frequency of the back-and-forth oscillation. The acceleration increases with the square of the frequency. This leads to the important result that the electromagnetic energy radiated by an oscillator increases very rapidly—namely, with the square of the square or, as one says, with the fourth power of the frequency. Doubling the frequency thus produces an increase in radiated energy by a factor of 16.

This rapid increase in scattering with the frequency of electromagnetic radiation can be seen on any sunny day: it is the reason the sky is blue and the setting Sun is red. The higher-frequency blue light from the Sun is scattered much more by the atoms and molecules of the Earth's atmosphere than is the lower-frequency red light. Hence the light of the setting Sun, which passes through a thick layer of atmosphere, has much more red than yellow or blue light, while light scattered from the sky contains much more blue than yellow or red light.

Significance of the scattering process

The process of scattering, or reradiating part of the electromagnetic wave by a charge oscillator, is fundamental to understanding the interaction of electromagnetic radiation with solids, liquids, or any matter that contains a very large number of charges and thus an enormous number of charge oscillators. This also explains why a substance that has charge oscillators of certain frequencies absorbs and emits radiation of those frequencies.

When electromagnetic radiation falls on a large collection of individual small charge oscillators, as in a piece of glass or metal or a brick wall, all of these oscillators perform oscillations in unison, following the beat of the electric wave. As a result, all the oscillators emit secondary radiation in unison (or coherently), and the total secondary radiation coming from the solid consists of the sum of all these secondary coherent electromagnetic waves. This sum total yields radiation that is reflected from the surface of the solid and radiation that goes into the solid at a certain angle with respect to the normal of (*i.e.*, a line perpendicular to) the surface. The latter is the refracted radiation that may be attenuated (absorbed) on its way through the solid.

Superposition and interference. When two electromagnetic waves of the same frequency superpose in space, the resultant electric and magnetic field strength of any point of space and time is the sum of the respective fields of the two waves. When one forms the sum, both the magnitude and the direction of the fields need be considered, which means that they sum like vectors. In the special case when two equally strong waves have their fields in the same direction in space and time (*i.e.*, when they are in phase), the resultant field is twice that of each individual wave. The resultant intensity, being proportional to the square of the field strength, is therefore not two but four times the intensity of each of the two superposing waves.

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similar to that caused by increased temperature, but without elevated temperature. Although details of the mechanism of interaction of EM fields with cells remain unknown, the induction of the stress response appears to be an appropriate cellular response to a stimulus that is not normally part of its environment, and this may well provide a clue to the mechanisms involved.

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MS-20-4

THE BIOLOGICAL EFFECTS OF MICROWAVE RADIATION. S. Kwee[1] and P. Raskmark[2]. [1]Institute of Medical Biochemistry, University of Aarhus, DK-8000 Aarhus C, Denmark. [2]Institute of Communication Technology, Aalborg University, DK-9220 Aalborg Ø, Denmark.

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